

Commonality in Process Based Erosion Models, Obstacles and Opportunities

Fred A. Fox Jr., Wind Erosion Research Unit, 1515 College Avenue, Manhattan, KS 66502. E-mail: fredfox@weru.ksu.edu

The United States Department of Agriculture, Agricultural Research Service, has independently developed two daily time step, process based erosion models, one to address the erosion of soil by wind (WEPS – Wind Erosion Prediction System) and one to address the erosion of soil by water (WEPP – Water Erosion Prediction Project). The two models need to simulate many of the same processes in order to accurately predict the erosion potential. Development can be enhanced if common process simulation code is used in both models.

System States used in process based erosion modeling

The defining element in any process based erosion model is the erosion process. Erosion amounts are determined by the interaction of the erosion process and it's driving forces with the state of the erodable surface. Estimating erosion amounts for varied crop management systems requires an accurate description of the time evolution of the state of the erodable surface in response to both management practices and climate driving forces.

Shown below is a comparison of the system states used to describe an erodable surface in WEPS and in WEPP. They are divided into two groups, unique state variables and common state variables to highlight obstacles and opportunities respectively for commonality in erosion modeling.

WEPS	WEPP
Driving Force	
<ul style="list-style-type: none"> - Air density - Wind direction - anemometer height - aerodynamic roughness at anemometer site - Wind speed 	<ul style="list-style-type: none"> - rainfall depth - rainfall duration - rainfall peak intensity - melt water from snow accumulation - irrigation
Erodable Surface Characteristics	
- Simulation Region coordinates (x1,y1;x2,y2) and orientation angle from North	Not Used
For each barrier specified - Barrier location, height, porosity, and width	Not Used
For each subregion specified - Subregion coordinates (x1,y1;x2,y2) and all following state variables	For each overland flow element specified - overland flow element slope angle - overland flow element slope - overland flow element length and all the following state variables
<ul style="list-style-type: none"> - Biomass height, stem area index, and leaf area index - Flat biomass cover 	<ul style="list-style-type: none"> - residue mass and cover fraction - live crop biomass and cover fraction
- Allmaras random roughness	- random roughness

<ul style="list-style-type: none"> - Surface crust fraction and thickness - Fraction of loose material on surface - Mass of loose material on crust - Soil crust density and stability - Snow depth - Surface layer water content (hourly) 	<ul style="list-style-type: none"> - inter-rill erodibility - rill erodibility
<ul style="list-style-type: none"> - Ridge height, spacing and width - Ridge orientation (deg from north) 	For each contour ridge specified <ul style="list-style-type: none"> - contour slope angle, slope, length, ridge spacing, and ridge height
For each soil layer specified <ul style="list-style-type: none"> - thickness - bulk density - water content - fraction of sand, silt, and clay - very fine sand - rock volume - aggregate density stability and size distribution - wilting point water content 	For each soil layer specified <ul style="list-style-type: none"> - thickness - bulk density - water content - fraction of sand, silt, and clay - matrix potential - effective hydraulic conductivity - critical shear stress - fraction of organic matter

Processes modeled to predict evolution of system state in time

As was noted in a previous paper (Fox et al, 2000), many of the same processes are modeled in both WEPS and WEPP. Each process model was designed and tested to support the evolution of specific states unique to the erosion process being modeled. Decisions were made to combine sub-processes differently to capture significant state interactions while keeping computer time requirements at reasonable levels. Given that the models have been under development for the past 12 years during which time computer speed has been constantly increasing, the core design and selection of process models was very likely done with a strong consideration to meet computer time requirements by using a "reasonable approximation", not to capture process effects on the system state for the widest range of possible conditions.

Interestingly, a review of another ARS developed model, RZQM (Ma, 2001) reveals that in order to model chemical transport in soil, many of the same processes are modeled. The model processes are described as: Management - tillage, addition of manures, chemicals, or irrigation water; Potential Evapotranspiration; Sub-hourly processes - infiltration and runoff, soil water distribution, chemical transport, pesticide washoff, heat movement, actual evaporation and transpiration, plant nitrogen uptake, reconsolidation of tilled soil, and snowpack dynamics; Pesticide degradation on plant and residue surfaces and within soil layers; Organic matter / nitrogen cycle; Soil inorganic chemical equilibrium; Plant growth - Photosynthesis, nitrogen uptake, carbon and nitrogen partitioning, root growth, respiration, and mortality as influenced by temperature, soil water availability, and plant nutrient status. RZQM modelers used the same infiltration method as WEPP, the same soil water redistribution theory as WEPS and a much more complex evapotranspiration method than either WEPP or WEPS.

Spatial definitions and conflicts in process modeling

In WEPS and WEPP, processes are defined to account for changes of state and fluxes in either one or two space dimensions. One dimensional process models track changes in state and fluxes along a line, even though the results may be applied over an

area or volume. The table below summarizes the processes modeled and spatial dimensions modeled.

WEPS		WEPP	
Climate generation - daily precipitation, temperature, solar radiation	Point estimate assumed valid over wide area	Weather generation - daily precipitation depth, duration and intensity, temperature, solar radiation, and wind	Point estimate assumed valid over wide area
Wind generation - hourly wind for 16 cardinal directions	Point estimate assumed valid over wide area		
Hydrology – daily soil water balance of rainfall, snowfall, irrigation, plant water use, drainage	One dimensional model, vertical from atmosphere into soil	Winter processes - snow accumulation and melting, soil freezing and thawing (hourly time step)	One dimensional model, vertical from atmosphere into soil
		Irrigation - schedules irrigation based on soil state or fixed user provided schedule	Two and a half dimensional model, updates soil water balance in one dimension only
		Infiltration - Green Ampt equation, precipitation, snowmelt or irrigation event based	One dimensional, vertical from soil surface into soil
Soil surface water content – hourly modeling of evaporative flux	One dimensional model, vertical from atmosphere into soil	Overland flow hydraulics – sheet and rill flow	One dimensional down slope
		Water balance - daily soil water balance of infiltration, irrigation, plant water use, percolation	One dimensional, vertical from atmosphere into soil
		Subsurface hydrology - percolation, lateral flow, resurfacing and tile drainage	Two dimensional, Vertical into soil and horizontal down slope
Management – soil disturbance and biomass manipulation	One dimensional, vertical from crop into soil		
Soil - re-consolidation, re-aggregation of disturbed soil due to rainfall, drying, freeze/thaw, and freeze/dry events	One dimensional, vertical from soil surface into soil	Soil - disturbance by tillage and natural processes	One dimensional, vertical from soil surface into soil
Crop - date, water and temperature effects with additions for stem, leaf and reproductive mass partitioning	One dimensional, vertical from crop into soil	Plant growth - date, water and temperature effects, separate field crop and rangeland modules	One dimensional, vertical from crop into soil
Residue decomposition - surface and subsurface integrating water and temperature effects	One dimensional, vertical from surface residue into soil	Residue decomposition and management - surface and subsurface integrating water and temperature effects	One dimensional, vertical from surface residue into soil

Erosion – subhourly soil movement in saltation, creep, suspension, and pm-10 components	Two dimensional, over modeled surface	Hillslope erosion and deposition - event based calculation of soil detachment and movement in sheet and rill flow	One dimensional, down hillslope
		Watershed channel hydrology and erosion processes and watershed impoundments.	One dimensional, along channel centerline

Technical impediments to common code

Conceptually, process modeling can be divided into the data inputs required to model the process, the algorithms to implement that process and the states modified by the process. WEPS and WEPP are coded primarily in FORTRAN 77, where the same concepts are embodied in subroutine (or function) calls (conceptually algorithms) and a combination of arguments and common blocks (conceptually the data inputs and states modified).

Model logical structure

Based on the number of common processes represented, it is hoped that the logical structure of the two models would be very similar. This is indeed the case. At the heart of the simulation, the state of a single simulation area is updated using a daily and sub-daily loop. A comparison of time scales and process ordering used in the two models follows:

WEPS	WEPP
do all subregions hydrology - subdaily calculations management - tillage, planting, harvesting soil - weather processes crop - plant growth decomposition end do erosion	do overland flow elements decomp - tillage and weather process residue effects soil - tillage and weather process soil effects aspect - solar energy balance winter - energy balance in winter - subdaily calculations irrig - irrigation flows irs - infiltration runoff simulation watbal - soil water balance newtil - plant growth end do route - sediment routing down hillslope sloss - resultant sediment loss on hillslope watershed - channel and impoundment routing

Model code structure

The degree of impediment to using common code for processes common to both models is directly proportional to the magnitude of common block usage. Implementing a common module requires defining the module with the appropriate input and output definitions, passed to the module as parameters, and then implementing WEPS or WEPP wrapper code to include the appropriate common blocks and pass the values to the common module. Common blocks are heavily used in present model implementations.

Opportunities

The comparisons above reveal several patterns in the implementation of erosion model code. Opportunities for employing common code are clearly shown in areas where the space, time dimensionality is the same and where the processes are similarly modularized. Climate generation of all but wind are external modules and are presently common. The plant growth process is the most likely candidate for common code being modularized identically. Management processes and their effect on crop, soil and residue are the next logical candidates, with a different modularization of the sub-elements, but full encapsulation of the overall process effects. A common module would need to include additional elements to describe the states needed for both erosion modules. The most beneficial and most difficult process to make common is hydrology. Spatial definitions are in conflict and the time scales vary for different elements. With continued development of process based models, analyses similar to this should be done to minimize the reinvention and re-implementation of modeling code and promote cooperative development efforts.

References

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